UNIVERSITY OF RUHUNA

BACHELOR OF SCIENCE GENERAL DEGREE LEVEL II(SEMESTER I) EXAMINATION JULY 2014

Subject:PHYSICS
Course Unit: PHY2114

Time: Two hours & 30 minutes

Part II

Answer FIVE(05) questions only
At least 01(ONE) question from Part B should be answered.

All symbols have their usual meaning

Part A

1. (a) Define the thermal resistance (R value) of a heat conducting rod identifying each term.

   (b) End temperatures of a rod of thermal resistance R are T_L and T_R ($T_L > T_R$) respectively. The rate of conductive heat transfer through the rod is given by

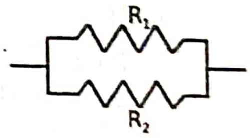
   $$\frac{dq}{dt} = \dot{Q} = \frac{T_L - T_R}{R}$$

   If there are n rods of identical cross sectional area are connected in series, use the above result to show that the rate of conductive heat transfer through the system is given by

   $$\dot{Q} = \frac{|\text{Terminal temperature difference}|}{\sum_{i=1}^{n} R_i}$$

   Here R_i is the thermal resistance of i^{th} rod. Assume that there is no heat transfer to the surrounding from the rods.

   (c) Figure shows two thermal resistors connected in parallel.

   Show that the resultant thermal resistance (R) is given by

   $$R = \frac{R_1 R_2}{R_1 + R_2}$$

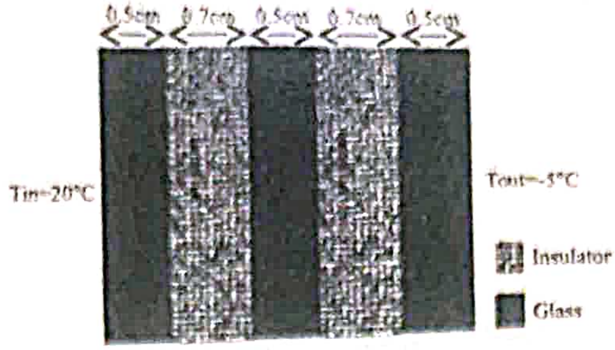
   (d) A window(width=2 m, height=2 m) has three glass layers and two thermal insulating layers as shown in the figure. The temperature inside the room is 20 °C and the environmental temperature is −5 °C.

   i. Draw the thermal resistance circuit for the window. If thermal conductivities of glass and insulator are 0.3 W m^{-1} K^{-1} and 0.02 W m^{-1} K^{-1} respectively, calculate the resultant thermal resistance of the window.

   ii. Calculate the rate of heat conduction to outside through the window.

   iii. Calculate the temperatures of each glass-insulator interfaces.

iv. Draw the thermal resistance circuit for a room, which consists of three such windows and find the total rate of heat loss through the windows.



2. (a) Write down the first law of thermodynamics describing each term.

   (b) An ideal gas expands

      i. adiabatically from (P_1, V_1, T_1) to (P_2, V_2, T_2).

      ii. isothermally from (P_1, V_1, T_1) to (P_3, V_2, T_1).
      IF P_2 and P_3 are less than P_1, indicate the above two processes in a $V - P$(volume Vs pressure, V-verticle axis) diagram.

   (c) One mole of an ideal gas ($\gamma = \frac{5}{3}$) at (P_1, V_1, T_1) is capable of executing following processes.
   $A \longrightarrow B$: the gas undergoes an isothermal process until its volume becomes $0.25V_1$.
   $B \longrightarrow C$: the gas undergoes an isochoric process.
   $C \longrightarrow D$: the gas undergoes an isobaric process until its volume becomes $0.75V_1$.
   $D \longrightarrow A$: the gas comes back to the initial state through an adiabaic expansion process.
   If the AB curve crosses the line CD at E, draw a $P - V$ diagram for the above cyclic process.

      i. Find pressure and volume after each process in terms of P_1 and V_1.

      ii. Find pressure and volume at point E in terms of P_1 and V_1.

      iii. Obtain an expression in terms of P_1, V_1 and T_1 for the work done by the gas (W) during this cyclic process.

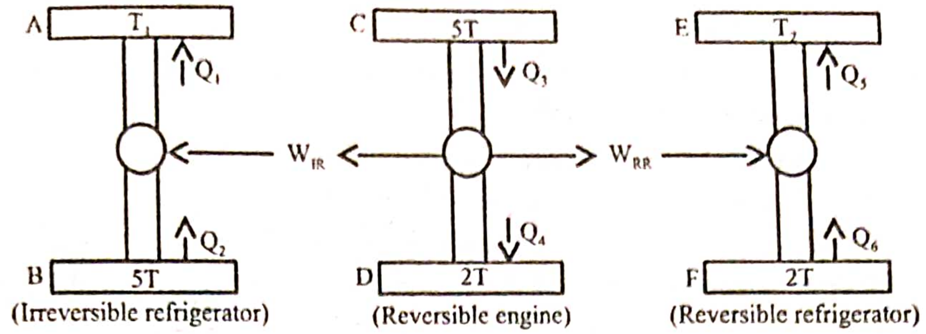
      iv. If $P_1 = 1.5 \times 10^5\,\mathrm{N\,m^{-2}}$, $V_1 = 1000\,\mathrm{cm}^3$ and $T_1 = 227\,^{\circ}\mathrm{C}$, calculate W.
      [When 1 mole of an ideal gas changes its state from (P_1, V_1, T_1) to (P_2, V_2, T_2), the work done by the gas during isothermal and adiabatic processes are given by $W = RT \ln \frac{V_2}{V_1}$ and $W = \frac{(P_2V_2 - P_1V_1)}{(1-\gamma)}$ respectively. Universal gas constant $(R) = 8.314\,\mathrm{J\,K^{-1}\,mol^{-1}}$]

3. (a) State and derive Carnot theorem.

   (b) The efficiency (η) of any heat engine is < 1 and the coefficient of performance (K) of a refrigerator is ≤ 1 or ≥ 1. Explain this briefly.

   (c) Write down an expression for the coefficient of performance of a reversible refrigerator in terms of the temperatures of hot and cold reservoirs.

   (d) Following figure shows an irreversible refrigerator and a reversible refrigerator operated using a reversible engine.



i. Is it possible to operate a heat engine between the reservoirs D and F? Explain your answer.

ii. Calculate the efficiency of the engine.

iii. If the coefficient of performance of the reversible refrigerator is 1, calculate T_2 in terms of T.

iv. If the maximum efficiency that can be obtained by a different hypothetical engine operated between the reservoirs A and C is $\frac{1}{2}$, calculate T_1 in terms of T.

v. If the coefficient of performance of the irreversible refrigerator is 1 and $W_{IR} = 200\,\text{J}$, calculate Q_1 and Q_2.

vi. If $W_{RR} = 100\,\text{J}$, calculate Q_3, Q_4, Q_5 and Q_6.

4. (a) Write down first and second TdS equations.

(b) Obtain the internal energy equation.

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$$

(c) i. The internal energy of an ideal gas depends only on the absolute temperature.

ii. The internal energy of a real gas depends on both the absolute temperature and the volume.

Describe the physical meaning of above two statements.

(d) Using the result in part (b) show that

$$\left(\frac{\partial U}{\partial V}\right)_T = 0$$

for an ideal gas

(e) Van Der Waals gas equation is given by

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT$$

If the the heat capacity of the gas (C_V) does not depend on the temperature, show that the internal energy of the gas is given by

$$U = C_V T - \frac{a}{V} + constant$$

5. (a) Derive the Clausius Clapyron's equation.

(b) Discuss the effect of pressure on melting points and boiling points of substances by usin the Clausius Clapyron's equation.

(c) Following figure shows a pressure cooker.

i. Discuss the importance of a pressure cooker.

ii. Usually a pressure cooker is made by thick allu-minium plates. Explain the reason for this.

iii. When water boils in the above pressure cooker the pressure meter indicates 1.2 atm. Calculate the boiling temperature of water inside the pressure cooker.

Specific volume of steam $=1.68\,\mathrm{m^3\,kg^{-1}}$

Latent heat of vaporization of water $(L)=2.27\times 10^6\,\mathrm{J\,kg^{-1}}$

Density of water $(\rho)=1000\,\mathrm{kg\,m^{-3}}$

$1\,\mathrm{atm} = 1\times 10^5\,\mathrm{N\,m^{-2}}$

6. (a) What is meant by entropy?

(b) State and derive the Clausius theorem. Hence, show that the entropy is a state function.

(c) m_1 kg of ice at $-T$°C is placed in thermal contact with m_2 kg of steam at 100°C. If you expect T°C of water at the equlibrium state,

i. Show that $T = \left(\frac{m_2 L_S + 100 m_2 C_W - m_1 L_I}{m_1 C_I + m_1 C_W + m_2 C_W}\right)$°C

ii. If $m_1 = 1.0\,\mathrm{kg}$ and $m_2 = 0.15\,\mathrm{kg}$, calculate the value of T

Specific heat capacity of ice $(C_I) = 2095\,\mathrm{J\,kg^{-1}\,K^{-1}}$

Latent heat of fusion of ice $(L_I) = 3.352\times 10^5\,\mathrm{J\,kg^{-1}}$

Latent heat of vaporization of water $(L_S) = 2.263\times 10^6\,\mathrm{J\,kg^{-1}}$

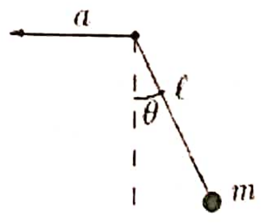
Specific heat capacity of water $(C_W) = 4190\,\mathrm{J\,kg^{-1}\,K^{-1}}$

Part B

7. A simple pendulum with mass m and length l is suspended from a point which moves horizontally with constant acceleration a as shown in the figure

(a) Show that the lagrangian for the system can be written, in terms of the angle θ,

$$L(\theta,\dot{\theta},t) = \frac{m}{2}(l^2\dot{\theta}^2 + a^2t^2 - 2alt\dot{\theta}\cos\theta) + mgl\cos\theta$$



(b) Determine the Euler-Lagrangian equation for the system.

8. The potential energy of a mass m moving in one-dimension when it is at a distance r from the origin is given by

$$U(r) = U_0\left(\frac{r}{R} + \lambda^2\frac{R}{r}\right),$$

where $0 < r < \infty$, and U_0, R and λ all positive constants.

(a) Find the equilibrium position r_0 of the mass.

(b) Find its potential energy at equilibrium position.

(c) Show that the angular frequency of small oscillations of the mass is given by

$$\omega = \sqrt{\frac{2U_0}{m\lambda R^2}}$$

9. A uniform distribution of dust in the solar system adds to the gravitational attraction of the sun on a planet an additional force

$$\mathbf{F} = -mC\mathbf{r}$$

where m is the mass of the planet, C is a constant proportional to the gravitational constant and the density of the dust, and $\mathbf{r}$ is the radius vector from the sun to the planet (both considered as points). This additional force is very small compared to the direct sun-planet gravitational force.

(a) Show that the equation of motion for r is given by

$$m\ddot{r} = \frac{l^2}{mr^3} - \frac{k}{r^2} - mCr$$

(b) Show that the period for a circular orbit of radius r_0 of the planet in this combined field is given by

$$T = \frac{2\pi}{\sqrt{\frac{k}{mr_0^3}}\sqrt{1 + \frac{mCr_0^3}{k}}}$$